BEAM SLICE CHARACTERIZATION AT SPARC HIGH BRIGHTNESS PHOTOINJECTOR*

B. Marchetti, A. Cianchi †, University of Rome Tor Vergata and INFN-Roma Tor Vergata
D. Alesini, M. Bellaveglia, E. Chiadroni, M. Castellano, L. Cultrera, G. Di Pirro,
M. Ferrario, D. Filippetto, G. Gatti, E. Pace, C. Vaccarezza, C. Vicario
INFN/LNF, Frascati (Roma)
L. Ficcadenti, A. Mostacci, University La Sapienza, Roma
C. Ronsivalle, ENEA C.R. Frascati, Frascati (Roma)

Abstract

The SPARC photoinjector drives a SASE FEL to perform several experiments both for the production of high brightness electron beam and for testing new scheme of SASE radiation generation. The control of the beam properties, in particular at the level of the slice dimension, is crucial in order to optimize the FEL process. We report some preliminary results concerning slice emittance and slice energy spread measurements. A comparison with PARMELA simulation is also given.

INTRODUCTION

The SPARC project is an R&D photo-injector facility for the production of high brightness electron beams to drive SASE and SEEDED FEL experiments in the visible and UV light. The high beam quality produced by SPARC will also allow investigations into the physics of ultra-short beams, plasma wave-based acceleration, and production of advanced X-ray beams via Compton back-scattering. In this stage of the beam commissioning, we began a detailed analysis of the beam matching with the linac in order to confirm the theoretically prediction of emittance compensation based on the 'invariant envelope' matching [1, 2] with and without the velocity bunching compression [3]. Also the first SASE radiation was produced. Preliminary results concerning the velocity bunching and the SASE radiation photon beam can be found in [4]. After this stage the machine will be also available for further experiments that use either the electron beam, or the photon beam.

The study of the beam slice properties, such as slice emittance or slice energy spread, allow to deeply investigate the details of emittance compensation method and to tune the machine for best performance. Moreover the knowledge of the beam current, beam energy, slice emittance and slice energy spread gives a complete description of the FEL process.

In this article we present the experimental results of slice emittance measurements in different scenario, in particular with different laser spot sizes on the photocatode. Also analysis of slice energy spread and comparison with simulation are shown.

* Work supported by MIUR Contract RBAP04XM5-001
† cianchi@roma2.infn.it

SPARC LAYOUT

SPARC is a normal conducting accelerator. The RF gun is one of the most recent generation 1.6 cell S-band BNL/UCLA/SLAC type followed by 3 S-band traveling wave accelerator constant gradient structures. Around the first and the second accelerating structure several solenoids are placed to provide additional focusing both for velocity bunching and matching the beam envelope with the linac according with the invariant envelope scheme. More details can be found in [4]. Typical operation energy is in the order of 140 MeV. For this stage of commissioning we have operated with a laser pulse with gaussian longitudinal profile of FWHM in the order of 6-8 ps. The bunch charge was around 200 pC. The laser spot on the cathode was around 300 μm rms.

SPARC DIAGNOSTIC

In order to achieve the SPARC goals a precise characterization of the beam parameters is needed. The beam envelope is measured in four different positions along the linac. The measurements of the beam envelope is mandatory in order to fulfill the requirements of the invariant envelope matching. Downstream the last section several diagnostic tools for a full characterization of the beam parameters are installed.

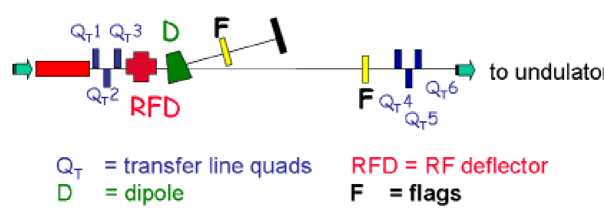

Figure 1: Layout of the experimental area at 150 MeV.

A triplet of quadrupoles is followed by the SPARC RF deflector, the dipole for the high energy measurement and the flags to evaluate the beam parameters (see Fig. 1).

The RF deflector (RFD), completely developed at SPARC, is a 5 cell standing waves structure reaching a maximum transverse deflecting voltage of more than 3MV with an input power of nearly 2MW. Further details can be found in [5].

The evaluation of the bunch length is mandatory especially in the studies of the velocity bunching. The RF deflector is used mainly for this task. The ultimate temporal resolution is affected not only from the deflecting voltage but also from the intrinsic vertical dimension of the beam size at the flag when the deflector is off. The transverse distribution of the bunch at the screen position is the superposition between the deflected beam size and the vertical dimension of the bunch σ_y at the flag position. The resolution can be defined as the bunch length giving on the flag the same vertical dimension of σ_y. In the actual condition the temporal resolution is estimated to be around 70 fs.

The quadrupoles are routinely used for the quadrupole scan in order to evaluate the transverse emittance. This technique allows, powering the RF deflector, also the investigation of the slice emittance.

Slice Emittance

The slice emittance is one of the fundamental parameter that define the FEL process. It also contains important beam dynamics signature. The technique is similar to the usual quadrupole scan [6]. Because the RFD deflect the beam vertically a set of values for the quadrupoles must be find in advance to change only the horizontal dimension of the beam, keeping constant the vertical size. A more detailed description of the slice emittance technique can be found in [7]. Different beam sizes and charge densities are used in order to compare several dynamics scenarios.

In the plot of Fig. 2 we compare the slice emittance measurement with a beam with 125 pC of charge and a laser spot on the cathode of 320X300 μm rms with a PARMELA simulation. The length of the error bars is the expanded uncertainty with Gaussian confidence level of 99%; the expanded uncertainty is obtained multiplying the standard uncertainty for a coverage factor depending from the confidence level and the measurement degrees of freedom according to [8]. The number of particles used in the simulation were Np=150k, the rms thermal emittance ϵ_{th}=0.75 mm-mrad per radius (mm) and the slice length 200μm.

In this plot we used a technique called rolling window. It is very hard, especially on the beam tails, determine the first and the last slice. This assumption however has impact on the position of all the other slices. To overcome this problem and to resolve the ambiguity we fix a slice length (in our case 200 μm) and we move it along the bunch in step of about 500 fs.

We collected measurements with three different laser rms spots: 320X300 μm, 260X225 μm, 205X175 μm. The beam charge were 125 pC, 90 pC and 60 pC. In Fig. 3 are reported the minimum values of the slice emittance for the three different situations, together with a PARMELA simulation using a value of the rms thermal emittance equal to 0.75 mm-mrad per radius(mm).

The value for the thermal emittance retrieved from the fit is (0.77 $\pm$ 0.02) mm-mrad per radius(mm). The excellent agreement, even if it is not conclusive, is an important

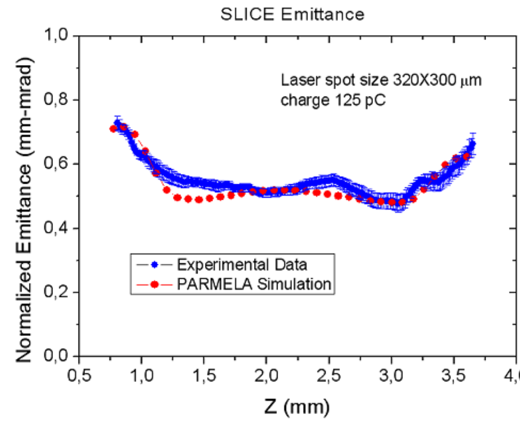

Figure 2: Comparison between slice emittance measurements and PARMELA simulation. Z is the longitudinal position along the beam

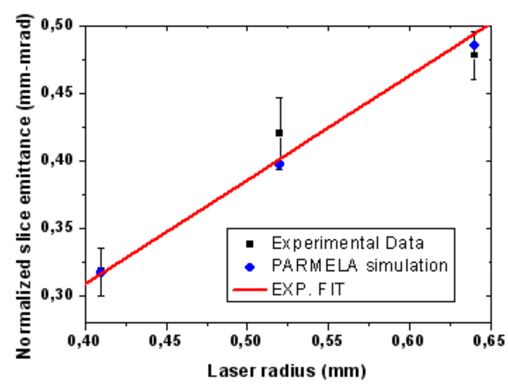

Figure 3: Comparison between minimum slice emittance measured and PARMELA simulation

indication that the only parameter that affects the smallest value of the slice emittance is the beam dimension on the cathode, and so the thermal emittance in the used beam charge range. Further investigation are underway.

Slice Energy Spread

The beam energy spread is a fundamental parameter in FEL photo-injectors. It determines the FEL process performances. The energy spread has to be kept small inside the FEL cooperation length. It gives a characteristic length in measuring slice energy spread, being the slice length in the order of the cooperation length. At SPARC the presence of a Radio Frequency Deflector with vertical deflection plane, followed by an horizontal dispersive region allows to measure the longitudinal trace space in a single shot. The measurement of the longitudinal trace space (see for example Fig. 4) gives both qualitative and quantitative information. The shape and the orientation are a useful tool to match the phases of the accelerating modules.

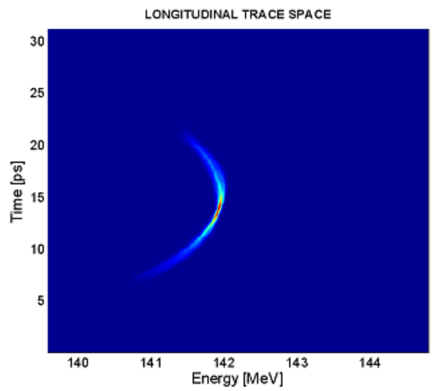

Figure 4: Longitudinal trace space at 140 MeV.

From a 2D analysis it is possible to retrieve the value of the longitudinal emittance to be compared with the simulation. In the case showed in Fig. 4 the measured value is around 209 mm-keV, only 5% greater than the simulated value.

From the trace space picture the slice energy spread can be extrapolated by slicing the beam vertically and measuring the beam thickness in energy as function of time. The slice length determines the thickness in time of each single slice. In order to characterize the beam out of the photoinjector, in the next plot the slice length has been chosen to be the smallest possible, given by the resolution, about 70 fs in time. The emittance contribution has not been subtracted from the measurements, but it has been estimated to be less than 10%.

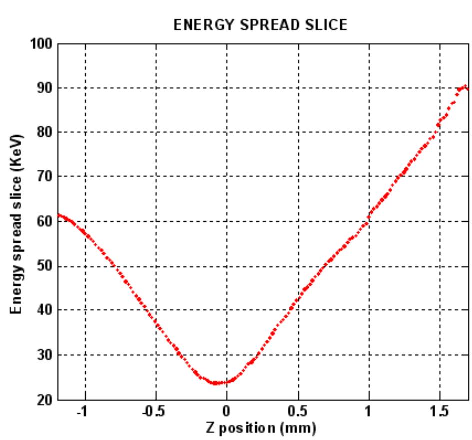

Figure 5: Measurements of the slice energy spread

While from the point of view of the FEL dynamics the slice length has a physical meaning due to the cooperation length, in term of machine studies we can push the slice dimension to the shortest value allowed by our system resolution in order to improve the knowledge of the beam dynamics.

The contribution of the RFD to the slice energy spread is not negligible. In the region close to the zero-crossing for the deflecting field, the accelerating field is zero on axis, but its derivative, with respect to the transverse coordinate is maximum. Thus off-axis particles experience different accelerating gradients. Moreover its dipole distribution enhances this process. This contribution depends linearly on the beam size inside the RFD, and it can be reconstructed from the beam dynamics model of the machine, after a previous emittance measurement.

In the actual working point of about 1.5 MV and with a beam size in the order of 300 μm rms inside the RFD, according to calculations of the induced energy spread [9], the resolution for the minimum slice energy spread is dominated by the induced spread in the RFD and can be estimated in the order of 15-20 keV that is indeed the minimum value measured. The simulation shows a minimum value of about 3 keV. Even if this affect the final resolution of the measurement, preventing the measurement of the right value, in term of FEL diagnostic it is meaningless, because its value is much smaller than the expected slice energy spread (140 keV). Further investigation are in progress to improve this resolution.

CONCLUSION

The measurements of the slice emittance and the slice energy spread are performed at SPARC to tune the machine to best performances studying beam dynamics, and to optimize the FEL process. Preliminary results reveal that interesting beam parameters can be measured in this way.

REFERENCES

[1] L. Serafini and J. B. Rosenzweig, "Envelope analysis of intense relativistic quasilaminar beams in rf photoinjectors:mA theory of emittance compensation ",Phys. Rev. E 55 (1997) 7565

[2] M. Ferrario, "HOMDYN Study for the LCLS RF Photo-Injector",SLAC-PUB-8400 (2000)

[3] L. Serafini and M. Ferrario, "Velocity bunching in photo-injectors", AIP Conference Proceedings 87 (2001) 581

[4] M. Ferrario and al.,'Recent Results of the SPARC FEL Experiments', these proceedings

[5] D. Alesini and al., "RF deflector design and measurements for the longitudinal and transverse phase space characterization at SPARC ",Nuclear Instruments and Methods in Physics Research A 568 (2006) 488

[6] M. Minty and F. Zimmermann, "Measurement and control of charged particle beams", Springer, 2003

[7] C. Vaccarezza et al, "'SLICE EMITTANCE MEASUREMENTS AT SPARC PHOTOINJECTOR WITH A RF DEFLECTOR", Proceeding of EPAC08, Genoa,1305 (2008)

[8] International Organization for Standardization et al., Guide to Expression of Uncertainty in Measurements ISO, Geneva, 2005.

[9] S. Korepanov, D. Alesini, et al. "AN RF DEFLECTOR FOR THE LONGITUDINAL AND TRANSVERSE BEAM PHASE SPACE ANALYSIS AT PITZ", DIPAC 2007, TUPB32